

## Optical Modulator And Method For Polarization Bit Interleaving

### Cross-Reference To Related Applications

[01] This application claims priority from US application No. 60/216,669, filed July 7, 2000.

### Microfiche Appendix

5 [02] Not Applicable.

### Technical Field

[03] The present application relates to optical communications using techniques for providing efficient high speed polarization bit interleaving.

### Background of the Invention

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[04] High-speed time-division-multiplexing (TDM) is a very attractive way of enhancing the spectrum efficiency of a large-capacity wavelength-division multiplexing (WDM) system. One common architecture employs two modulators having a same bit rate, wherein two separately modulated streams of data bits are combined into a high-speed single serial stream of data bits. Instead of providing a single higher-cost higher-speed modulator capable of providing modulation at a frequency of  $n$  Hz, two modulators having a frequency of  $n/2$  Hz are provided and their outputs are time-interleaved providing a signal having a frequency of  $n$  Hz. However, one drawback to such a scheme, particularly in high-speed dense systems is that pulses from adjacent time slots spread and partially overlap one another and detection errors sometimes occur at a receiver end.

20 [05] One remedy for this is provided by an enhanced TDM system wherein adjacent interleaved pulses are distinguishable as they are orthogonally polarized. Such a scheme is described in a paper entitled 1.04-Tbit/s SWDM Transmission Experiment Based on Alternate-Polarization 80-Gbit/s OTDM Signals, by Yutaka Miyamoto et al., published in ECOC'98 20-24 September 1998 Madrid, Spain. In this paper alternate-polarization optical-TDM is described to  
25 increase the bit rate while keeping the signal spectrum from broadening. Here two modulated

signals are time-division multiplexed with additional enhancement being achieved by polarization multiplexing of the two interleaved TDM streams.

**[06]** Another system using enhanced polarization optical TDM is described and illustrated in U.S. Patent No. 5,111,322 in the name of Bergano et al, entitled Polarization Multiplexing

5 Device with Solitons and Method Using Same, incorporated herein by reference. In this patent, a transmission system's capacity is increased by using a combination of polarization and time-division multiplexing. More specifically, two streams of differently (preferably orthogonally) polarized solitons are interleaved (time-division-multiplexed) at a transmitter, and later separated at the receiver to recover both data streams.

10 **[07]** Fast modulators (eg.40 Gbit/s), with a potential of up to double this rate) are also available instead of time division multiplexing signals from two slower modulators. However, problems of pulse broadening and jitter in a high speed pulse stream cause the pulses to begin to overlap and act coherently causing non-linear interactions and interference with the result that the signal cannot travel as far with an acceptable error rate as slower bit rate systems. Polarization multiplexing, as disclosed in US 5,111,322 prevents the non-linear interactions. Since the alternately polarized pulses cannot interact, the signal can travel farther at the same bit error rate. The method of providing the polarization multiplexing taught by Bergano, however, is difficult to realize.

15 **[08]** The Bergano device, shown in prior art Fig. 1, provides a mode locked laser light source 201 which outputs a train of pulses at a pulse repetition frequency of, for example, 2.5 GHz, ie. half the desired rate of the output signal. The pulse train is then split by a polarization beam splitter 202 into two beams of equal amplitude having orthogonal polarization. Each beam travels through a data modulator 205,206 operating at the 2.5 Gbit/s rate. A delay line (not shown) is needed to ensure that the pulses in the two beams arrive at the two modulators 205,206  
20 simultaneously. At the same time, the RF signals for both modulators also need to be synchronized with the pulses. At 2.5 Gbit/s this synchronization is not such a difficult problem as for a 40 Gbit/s system or faster. As further taught by Bergano, polarization controllers 211-214 are required to maintain the required linear polarizations. After passing through the data modulators 205,206, one of the pulse trains is delayed at delay line 209 by half of the period

enabling the two orthogonally polarized beams to be recombined at the polarization splitter 210 providing a signal output at 5 Gb/s.

[09] The use of two data modulators, in Bergano, and two associated drivers makes this system expensive and rather complex. Two broad band modulators, and two associated data drivers are required. The optical pulses in the two arms need to be synchronized with sub-picosecond accuracy to arrive at the modulators at precisely the same time. A further problem of electrical cross talk occurs between the two modulators, particularly in an integrated design. The mode locked laser has a modulation which must also be synchronized with the data modulators. This synchronization is somewhat more difficult. In addition, the RF data needs to be synchronized with the optical pulse trains with the same precision. This requires at least one, but usually two electrical delay lines. In addition, the powers in the two arms need to be equalized, usually requiring a variable optical attenuator in each arm.

[10] It is desired to provide a simple and economical device and method for providing polarization bit interleaving using a single data modulator.

### Summary of the Invention

[11] The present invention has found with the availability of fast data modulators, that polarization bit interleaving can be employed more efficiently for higher speed data transmission in optical network systems by providing an optical modulator including a single data modulator, rather than multiplexing different data streams from different modulators as taught in the prior art.

[12] Accordingly, the present invention provides an optical modulator for encoding data on orthogonally polarized alternate light pulses comprising:

means for modifying a laser light beam to a pulse train at a first frequency;

a data modulator for encoding signal data on the pulse train at a second data stream

frequency where the second frequency is greater than or equal to the first frequency;

means for rotating a polarization state of at least alternate light pulses of the pulse train to provide a data stream of orthogonally polarized alternate light pulses.

Thus an aspect of the present invention provides an integrated data modulator optical circuit comprising:

a laser light source;

a pulse generator comprising a first Mach-Zehnder device integrated on a substrate coupled to the laser light source for producing a pulse train;

a single data modulator comprising a second Mach-Zehnder device integrated on the substrate for encoding data on the pulse train; and

means for interleaving alternate pulses of orthogonal polarization onto a single pulse train comprising a third Mach-Zehnder device integrated on the substrate for separating alternate pulses, further including a polarization rotator for rotating at least alternate pulses and a polarization combiner for interleaving alternate pulses.

In accordance with the invention a method of encoding data on a light pulse train of alternate polarization interleaved bits comprises the steps of :

providing a pulse train of light pulses at a first frequency;

encoding data on the pulse train at a second data stream frequency where the second frequency is greater than or equal to the first frequency;

passing at least alternate pulses through a polarization rotator to rotate alternate pulses to orthogonal polarization states; and

interleaving the orthogonally polarized pulses, for transmission in an optical system.

### **Brief Description of the Drawings**

[13] Further features and advantages of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

[14] FIG. 1 is a prior art optical modulator for providing polarization interleaving including two data modulators;

[15] FIG. 2A is a schematic illustration of an optical modulator for polarization interleaving in accordance with the present invention;

[16] FIG. 2B is a schematic illustration of a bulk optic polarization delay line suitable for use in the embodiment of Fig. 2A;

[17] FIG. 3 is a detailed schematic illustration of a further embodiment of the optical modulator in accordance with the present invention; and

[18] FIG. 4 is a schematic illustration of an integrated layout for use with the present invention.

5 [19] Throughout the drawings like features are identified by like reference numerals.

### Detailed Description of Preferred Embodiments

10 [20] Fig. 2A shows a general schematic illustration of the optical modulator 10 for polarization interleaving using a single data modulator. The modulator 10 includes a continuous wave laser 12 and a pulse generator 14. The pulse generator 14 provides a pulse train at 20 GHz. The train of pulses is input into a polarization delay line 16 at 45 degrees to the principal axes. The delay line 16 orients the orthogonal polarization states and delays one component by 25 ps (eg. half the period of the pulse train) with respect to the other. The train of pulses exiting the polarization delay line 16 consists of pulses of alternating orthogonal polarizations and equal amplitudes combined now at 40 GHz. This pulse train is provided to the data modulator 18 for data encoding and launching onto the optical transmission network. This embodiment has the advantage of a simple design which can be integrated on a single substrate. The use of a slower pulse generator further reduces the cost of the device.

15 [21] The pulse generator 14 is a Mach-Zehnder type modulator. A mode locked laser can also replace the laser and pulse generator to produce a pulse train. A mode locked laser advantageously generates a narrower pulse. However, modulators of the  $\text{LiNbO}_3$  balanced Mach-Zehnder type are preferred as they produce very low chirp of the light pulses. Of course, other types of modulators may be used, for example electro-absorption or GaAs. The use of Mach-Zehnder modulators on lithium niobate substrate, facilitates construction of the device as an integrated optical modulator on a single substrate.

20 [22] The data modulator 18, which is conveniently also a Mach-Zehnder type modulator, requires a more complex driver in this embodiment, in order to provide different driving voltages for the different polarization states. Since this type of modulator is optimized for one polarization state, for the other of the polarization states, the required voltage will be quite high.

**[23]** The polarization delay line 16 may comprise a bulk optic device, or a long length of polarization maintaining fiber or a combination of the two. An example of a polarization delay line in a bulk optic device is shown at 26 in Fig. 2B, in which an input signal IN of linear polarization is passed through a polarization beam splitter 28 at an orientation of 45 degrees to the principal axis of the polarization beam splitter. The polarization beam splitter 28 is arranged to separate orthogonal polarizations and to pass one linear polarization state and reflect the other linear state. The polarization state which passes through, for instance horizontal, is reflected by a corner cube mirror 30 and joined through a second polarization beam splitter 32 with the other polarization state, in this case vertical, which is reflected by the polarization beam splitters 28,32. Thus, both horizontal and vertical polarization states are combined in a single output signal OUT with a relative delay due to the difference in path lengths.

**[24]** In operation in an optical network, the receiver is not polarization sensitive. Accordingly, the time interleaving of pulses of the present invention can be used simply to increase the data rate to a eg. 40 GHz receiver. Alternatively, the orthogonal polarizations can be separated and directed to two slower, eg. 20 GHz receivers.

**[25]** Fig. 3 shows an alternative embodiment of the invention. In this embodiment shown generally at 100, a continuous wave laser 120 provides light to a 40 GHz pulse generator 140. The 40 GHz pulse train is input into a broad band 40 Gbit/s data modulator 160. Following the data modulator 160, preferably on the same lithium niobate substrate, is a narrow-band Mach Zehnder type modulator 170, for separating alternate pulses. A micro-optic assembly butt coupled to the substrate of the Mach-Zehnder 170 rotates the polarization of half the pulses and recombines the pulses to a stream of alternate orthogonally polarized pulses. The narrow band nature of the signal permits use of narrowband modulation techniques for interleaving the alternate pulses. The pulse generator, data modulator and the narrow-band modulator can all be integrated on the same substrate.

**[26]** Modulator 170 is driven by a 20 GHz sine wave. The same synthesizer (not shown) can be used to drive both the pulse generator 140 and the modulator 170. A standard RF delay circuit 165 is incorporated to adjust the synchronization of the sine wave signal to the pulse train. Modulator 170 has a first output port 171 and a second output port 172. At the minimum of the

sine wave, the output is directed through the first port 171. At the maximum of the sine wave the output is directed through the second port 172. An output from the first port 171 is coupled on a first optical path through a half wave plate 174 which rotates the polarization of the pulses by 90 degrees. Polarization rotation can be achieved using a low order half wave plate, or a quartz polarization rotator. Polarization rotation can also be performed within the lithium niobate waveguide. An output from the second port 172 is coupled on a second optical path, through a spacer 176 to maintain an equal path length, to the first optical path. Light from the first optical path and the second optical path is combined in a polarization beam combiner 178, such as a birefringent crystal or a cube beam splitter with a polarization coating, and launched as a 40 Gb/s data stream of alternate orthogonally polarized pulses.

**[27]** By integrating the pulse generator, data modulator and the narrow band Mach Zehnder on the same substrate and using micro optics for beam steering, polarization rotation and beam combining, and time delay or synchronization a very compact device is created. In order to obtain sufficient length on the substrate, a double path across a smaller substrate is provided with a device for redirecting the pulse stream from the first path back to the second. A simple device for reversing the direction of beam travel is shown generally at 190 in Fig. 4, in combination with two modulator devices 191, 192 on a lithium niobate substrate 198. A quarter pitch GRIN lens 194 is butt-coupled directly to the substrate 198 substantially symmetrically between the modulator devices 191, 192. A broadband reflective coating 196 is deposited directly to the back surface of the lens 194. The diverging light from the first device 191 is collimated by the lens 194, reflected from its back surface 196, and re-focused into the second device 192.

**[28]** In an integrated design the polarization states are maintained throughout the device by the integrated waveguides. In a non-integrated embodiment, individual modules are coupled with polarization maintaining fiber. In both cases, the output signal is launched into single mode fiber without polarization control.

**[29]** The embodiments of the invention described above are intended to be exemplary only. The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.